time. Having the true orbital element set of a satellite at an instant in time incurs no errors, as compared with NORAD's mean set of elements.

The 2LMES is generated using a differential corrections scheme, simply Newton's method. Newton's method is a "quick and dirty" calculation that provides adequate results. NORAD uses historical data to help correct the elements by comparing it to actual orbit data and predicted data. This must be done to compensate for the mean elements.

Numerical integration generates more accurate element sets for osculating elements using Predictor-Corrector methods (i.e., weighted least squares). These methods correct for the position errors, including the weighted errors from the ground station. For GPS, the result is a postion vector typically within 20 m of its actual position as discussed previously.

Orbit Propagation

If NORAD propagates it's 2LMES analytically, typically with SPG4, all the errors from the observables are propagated with the elements, as described above. As a result, the length of time that a satellite's orbit can be propagated is based on the position tolerances required for the satellite and how fast the errors propagate.

Given more accurate observables (as described above), numerical integration can propagate the satellite's orbit for longer periods of time. One highly accurate method for propagation is Cowell's method as described above. Cowell's method numerically integrates the orbit's motion and perturbation accelerations at the same time. The

accuracy obtained for this method is within 100 meters of the true orbit for as long as 2

to3 weeks for LEO satellites.

It is recommended that the use of NORAD's 2LMES be avoided as providing

low orbit prediction accuracy. A state vector or a ranging approach is recommended as

the format for obtaining the observables. The element set should use numerical

integration to perform both orbit determination and orbit propagation (Cowell's method).

The result can be orbit prediction within 100 meters of the actual orbit for a period longer

than two weeks. Moreover, there are good orbit determination and propagation COTS

tools available today. These tools can and will be utilized to perform Leo One USA's

orbit calculations.

3. <u>Sharing With the Radio Navigation Satellite Service</u>

NVNG MSS systems can share with RNSS satellite systems. However, this

sharing will impose certain burdens on the NVNG MSS operator. The fact that the U.S.

Transit satellite system will have vacated the Transit band by the end of 1996 is of little

consequence when considering the significant interference imposed by the Russian RNSS

satellite system to Little LEO satellite uplink receivers. The ITU working groups have

concluded that sharing between maritime and aeronautical MSS stations (Earth to Space)

with existing RNSS systems in the 149.95 - 150.05 MHz and 399.9 - 400.05 MHz bands

is impractical because of the required coordination distances.[8] It also concludes the MSS

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[8]The coordination distances required range from 180 to 360 km for subscriber terminals and up to 660 km for gateways. See "Methodology Of Estimating Feasibility Of Sharing Between MSS Systems and Existing RNSS Systems in the Frequency Bands 149.-150 MHz and 399.400.05 MHz", ITU Doc. 8D/TEMP/123-E, 5 Nov. 1996.

LEO spaceborne receivers will be subject to strong interfering signals from these Russian Navsats (Their altitude is 1000 km, 83° inclined, passing in close proximity to Leo One USA's satellites at 950 km altitude). The Russians have indicated their intention to maintain 10 navigation satellites, one in each of 10 orbit planes. Because the signals from these satellites span the proposed System 3 uplink band and interfere with uplink reception, any Little LEO system would frequently have to shut down or avoid these signals during each orbital revolution.

In general, the best strategy for sharing this band appears to be to step around those RNSS satellite frequencies in the Little LEO horizon. Figure 31 shows the RNSS satellites in-view of a Leo One USA satellite (Satellite 5/1) as a function of time, shown here over 24 hours (a day in the life of a Leo One USA satellite).

Leo One Satellite LOS Contact Time With
Russian Navsats

Leo One Plane 5-1 Satellite
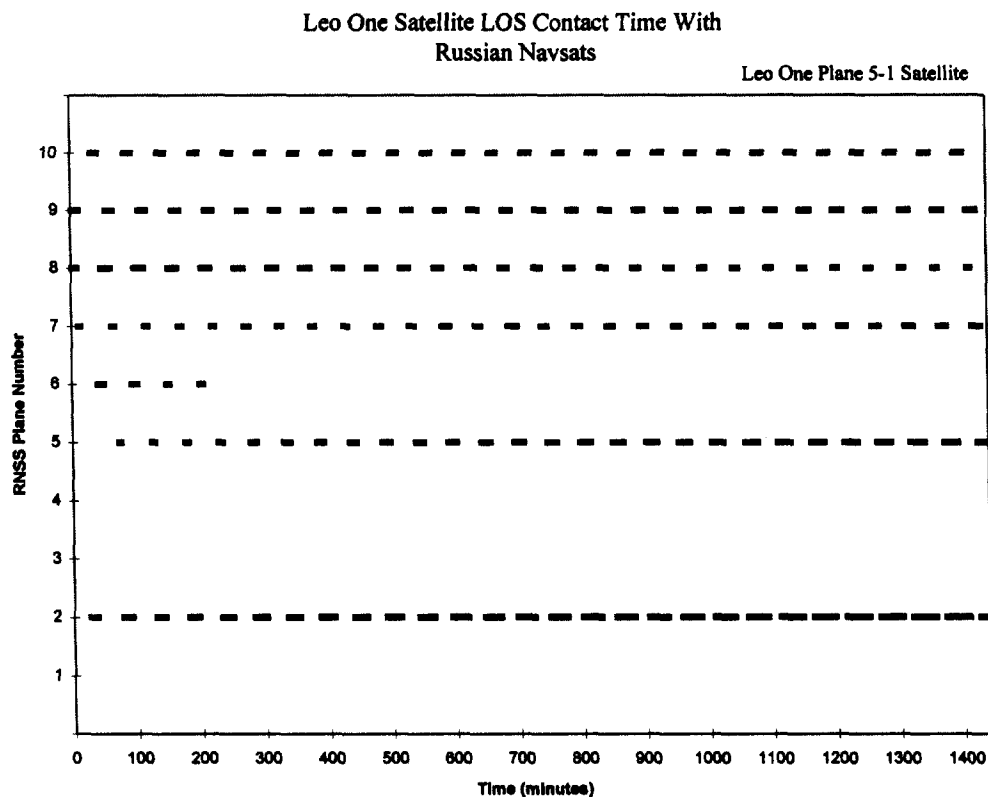
**Figure 31. RNSS Interference Intervals To One
Leo One USA Satellite Over One Day**

A variety of different contact situations can occur. There are other situations where a Leo One USA satellite travels within the horizon of an RNSS satellite for over a day. Note the repetitive nature of the recontact time of approximately twice per rev for many of the RNSS satellites shown in this figure. As shown, at times there are as many as 5 RNSS satellites in a Leo One USA satellite radio horizon at one time. This has the potential of blocking the entire band proposed for System 3 for a significant percentage of time. Thus, the true capacity of the available 100 kHz bandwidth will be considerably reduced and has been determined to be less than 50% of what would be available with otherwise clear spectrum. Sharing of this limited band capability is extremely difficult because of the limited spectrum and the dynamic time varying nature of the useable spectrum during each orbital revolution. Nevertheless, with proper satellite design, the use of good engineering practices and a suitable channel assignment plan it should be possible for an NVNG MSS system to use the 149.95-150.05 MHz band.

APPENDIX F

APPENDIX F

PERFORMANCE ATTRIBUTES OF PROPOSED SYSTEM A AND SYSTEM B

1.1 Introduction

The spectrum assignments proposed in the Notice for System 1, System 2 and System 3 do not make efficient use of the available spectrum, will not support economically viable competitors, cannot serve maritime and aeronautical markets, and cannot provide near real-time performance. Leo One USA recommends an alternative proposal that maximizes the efficient use of the spectrum and supports two economically viable systems: System A and System B. The following discussion of the performance of these new proposed systems shows near real-time performance is possible. In Appendix B, Leo One USA demonstrated that Systems A and B provide up to 90 and 92 percent of the capacity of Orbcomm, respectively. Equally important, both System A and System B are able to serve land, maritime and aeronautical markets, effectively fostering competitive NVNG MSS services. Leo One USA demonstrates below how it would make effective use of this recommended spectrum allocation.

The current Leo One USA system design provides the highest service availability of all of the NVNG MSS applicants. Consequently, the Commission's proposed sharing mechanisms has the greatest impact on Leo One USA. Thus, in this analysis Leo One USA is used as a benchmark against which the sharing approach and achievable service availability are measured. The analysis indicates the sharing impact is minimal and acceptable. Table 1 summarizes the Leo One USA system parameters used in this analysis.

Table 1. Leo One USA System Parameters[1].

Parameters	NVNG System
Total No. of Satellites	48
Total No. of Planes	8
Altitude	950 km
Eccentricity	0
No. of Planes	8
Sats. per Plane	6
Inclination	50°
RAAN	0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°
Intra-plane Sat. Spacing	60°
Inter-plane Sat. Spacing	7.5°
Argument of Perigee	0.0°
Orbit Period	103.8 min
Gateway Downlink Channel Bandwidth	60 kHz
Service Downlink Channel Bandwidth	35 kHz

1.2 System A Attributes

The proposed System A uses the combined downlink spectrum of System 1 and System 3. For the uplink it is proposed that the spectrum available for narrowband operation be used equally by System A and System B.

Specifically for the downlink, it is proposed the 400.15-400.505 and 400.645-401 MHz bands will be time shared with the DMSP satellites, and the 400.505-400.5517 MHz band will be time shared with VITA. This sharing will be on a non-interference basis to the DMSP and VITA systems.

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[1] At 400 MHz, the necessary channel bandwidth is 35 kHz for the subscriber channels and 60 kHz for the gateway channels due to the higher Doppler guard band requirements at 400 MHz.

For the Uplink, it is proposed the 150.00-150.05 MHz band segment, which is allocated for LMSS (no maritime or aeronautical use), will be time shared with the Russian Navigation Satellite System (RNSS), as well as with land mobile radios in most countries. The 149.81-149.855 MHz band segment will be time shared with VITA, and the 148.905-149.81 MHz band will be dynamically shared with Orbcomm and System B. This sharing will all be accomplished using dynamic channel assignment techniques. The VITA band segment is not shared with System B and the navigation band segment is not shared with System B or Orbcomm, allowing unique spectrum for protected links.

The DMSP MetSat band can be shared on a non-interference basis to the MetSats by using a frequency avoidance concept. This simplified frequency sharing concept requires the Little LEO satellites to step or hop to the opposite MetSat band segment whenever a MetSat coverage footprint overlaps that of a Little LEO satellite horizon. The coincidence times are readily precomputed and frequency selection instructions can be loaded into each satellite to span the duration of element set validity.

DMSP satellite ephemeris information is needed in order to predict the DMSP satellite locations. In order to ensure ephemeris prediction accuracy, weekly updates from DOD/DMSP are required along with the frequency being used by each satellite. It is assumed that the frequencies are not changed often and that weekly updates are acceptable, although more frequent updates could be accommodated.

It should be noted that for a five satellite DMSP system, the potential exists for two DMSP coverage zones to overlap a Little LEO horizon footprint, as shown in Figure 1, over CONUS. These coverage contours were obtained by using five of the DMSP satellites currently in orbit as representative of future orbital coverage. This overlap is assumed to result in total

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blockage of the Little LEO System in those areas where the dual DMSP overlap occurs (this is a worse case assumption). Any two DMSP satellites within the horizon coverage of a Little LEO satellite will potentially result in a blockage situation. This worse case analysis assumes the two DMSP MetSats in close proximity will use both portions of the band so as not to interfere with themselves, leaving System A without any available spectrum during this overlap period.

Under the assumption that the DMSP downlink frequencies in use will be provided to the Little LEO operator, it is possible to estimate user availability for the band hopping approach described. The availability to Leo One USA users is shown in Figure 2 for System A satellite coverages of 5, 10 and 15 degrees elevation angle and for DMSP coverage of 5 degrees without using the VITA channel. What would otherwise be 100 percent coverage at 40° latitude, if sharing with DMSP were not required, is reduced to approximately 77 percent at 15 degrees coverage as a result of the sharing with DMSP. This availability improves dramatically with the use of the VITA channel.
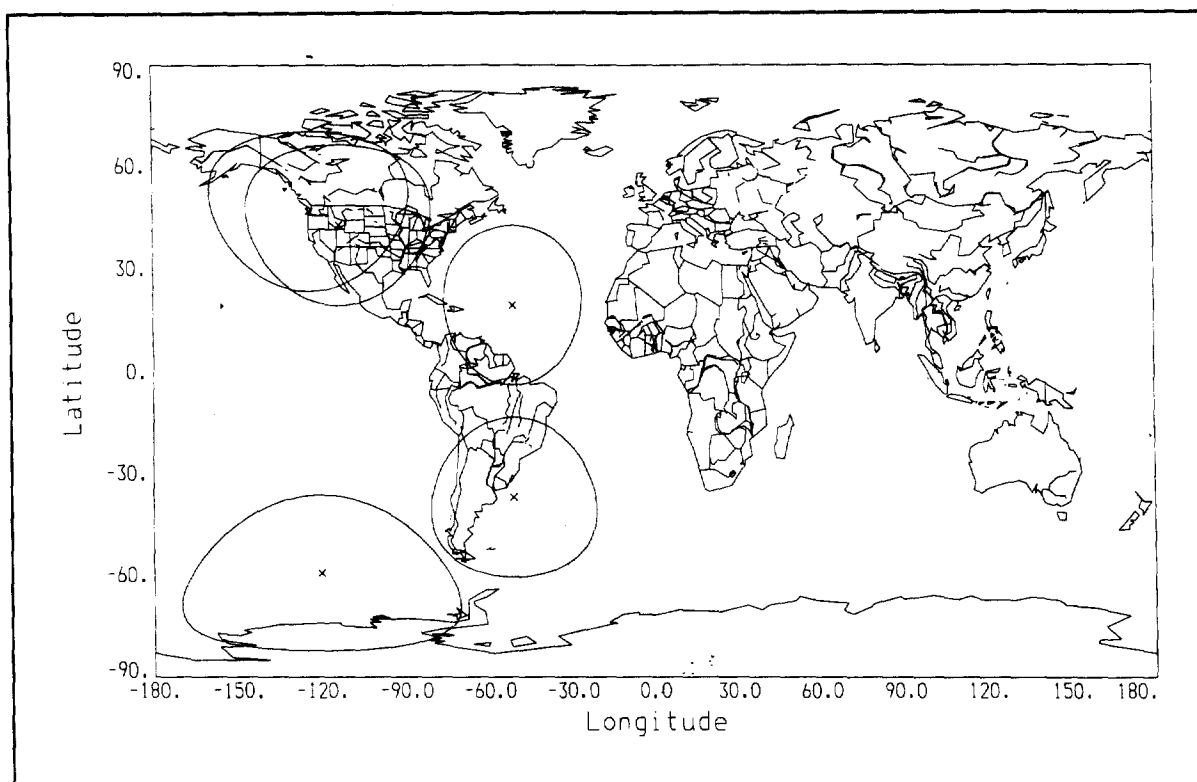
Figure 1. DMSP Five Satellite Constellation Coverage For 5° Elevation Footprint.

System A Availability

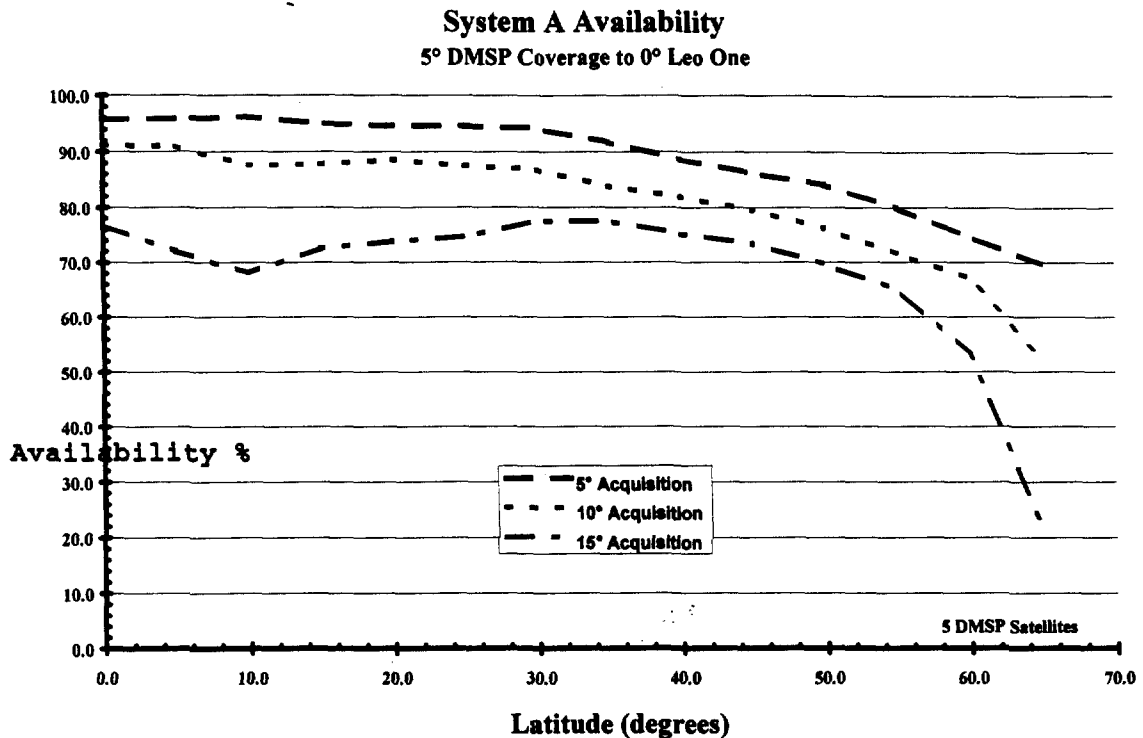5° DMSP Coverage to 0° Leo One

Figure 2. Availability For 5 DMSP MetSats Without Use Of VITA Channel.

In order to increase system availability to near real-time, sharing of VITA's channel is needed to assure a downlink subscriber channel for near continuous availability. The VITA channel is available most of the time since VITA is a one satellite system. This channel is sufficient to support one subscriber channel downlink, thus ensuring 100 percent availability of subscriber usage unless a VITA satellite coverage footprint is also overlapping with the System A interference footprint during a time of a dual DMSP overlap situation. During this occasional occurrence, System A would cease transmission and an outage would occur.

A significant improvement in availability is achieved using this System A allocation. Figure 3 is a plot of the availability for 5, 10 and 15 degrees Leo One USA coverage. The constellation availability at 40° latitude for a 5° DMSP coverage situation is increased to over

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97.5 percent from 88 percent for 5° System A coverage. For this analysis the VITA coverage is defined by a 5 degree elevation angle footprint. The significance of this improvement in availability for near real-time services can be readily appreciated. This demonstrates the importance of sharing the VITA channel.
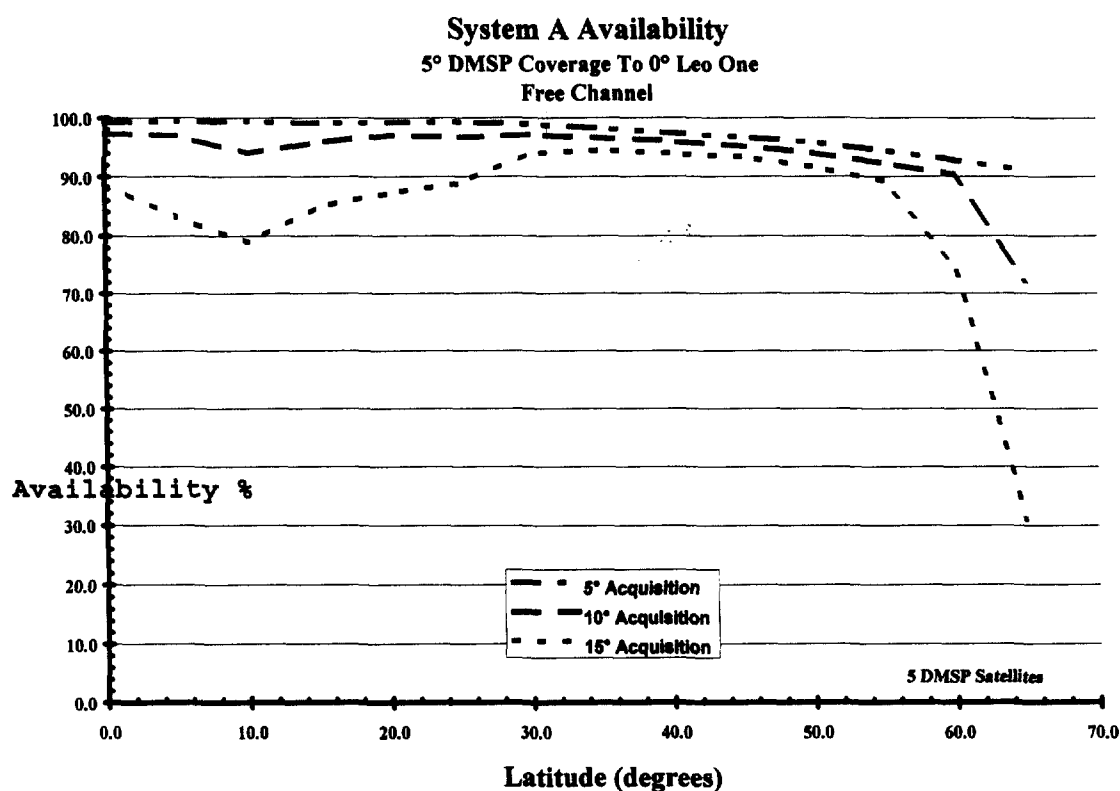
System A Availability
5° DMSP Coverage To 0° Leo One
Free Channel

Figure 3. Availability For 5 DMSP MetSats With VITA Channel Sharing.

1.3 System B Attributes

The proposed System B uses the downlink spectrum of System 2. For the uplink, it is proposed that the spectrum available for narrow band operation be used equally by System A and System B.

Specifically for the downlink, it is proposed the NOAA LRPT bands (137.025-137.175 MHz and 137.825-138.0 MHz) be used exclusively on a 100% availability basis until the first European METOP-1 MetSat is launched in 2002. This band would be time shared on a non-interference basis thereafter to all MetSats by using the opposite LRPT band when the Little LEO horizon coverage overlaps the MetSat footprint. NOAA will begin to launch its new satellites using the LPRT bands beginning in 2003. Once two MetSats begin using the LRPT band and 100 percent availability cannot be assured, it is proposed that the TIP channel (137.333-137.367 MHz and 137.753-137.787 MHz) sharing with NOAA begin. This will ensure that the availability remains close to 100 percent and near real-time services are preserved. As the older generation NOAA satellites fail or are turned off, the TIP channels will become available on an exclusive basis, and 100 percent availability is again achieved.

For the uplink, it is proposed the 149.95-150.0 MHz band segment, which is allocated for LMSS (no maritime or aeronautical use), will be time shared with the Russian Navigation Satellite System (RNSS) as well as with land mobile radios in most countries. The 149.855-149.9 MHz band segment will be time shared with VITA, and the 148.905-149.81 MHz band will be dynamically shared with Orbcomm and System A. This sharing will all be accomplished using dynamic channel assignment techniques. The VITA band segment and the navigation band

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segment are not shared with System A and the navigation band is not shared with Orbcomm, allowing unique spectrum for protected links.

Alternatively, System B can support a low power spread spectrum CDMA approach with the uplink operating on a shared basis with GE Starsys' CDMA in the 148-148.905 MHz spectrum or on a shared basis with System A and Orbcomm in the 148.905-149.81 MHz spectrum.

The NOAA MetSat downlink band can be shared on a non-interference basis to the MetSats using a frequency avoidance concept. This simplified frequency sharing concept requires the Little LEO satellites to step or hop to the opposite MetSat band segment whenever a MetSat coverage footprint overlaps that of a Little LEO satellite horizon. The coincidence times are readily precomputed and frequency selection instructions can be loaded into each satellite to span the duration of element set validity.

1.3.1 Sharing of NOAA LRPT or TIP Bands Individually

As the NOAA NPOESS MetSat LRPT band usage develops, the continued use by a Little LEO will result in a decreasing availability with time. Figure 4 is a plot of the Leo One USA system's availability calculated for sharing of the NOAA bands or channels with a 2, 3, 4 or 5 POES satellite constellation. The NOAA-14, NOAA-12, NOAA-11, NOAA-10, and NOAA-9 satellites were used for this availability calculation. The NOAA-14 (137.620 MHz) and NOAA-12 (137.500 MHz) satellites are the current two AM & PM operational satellites. The others are currently in standby and are used in the order listed as representative of future NOAA constellation growth. NOAA-K is planned to replace NOAA-12 in August 1997. The launch

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dates for the planned replacement satellites are NOAA-L (PM) in Dec. 1999, NOAA-M (PM) in April 2001, NOAA-N (PM) in Dec. 2003 and NOAA-N (PM) in July 2007. These last two N-series satellites being the new LRPT band satellites. The European METOP-1 and -2 satellites are planned as AM satellites for 2002 and 2006 and will use the new LRPT bands.

Figure 4 can also be used to interpret the availability if the TIP channels were shared instead of the LRPT bands. In using Figure 4 to interpret the availability when using the TIP channels, we have assumed the TIP signal is on continuously. Its usage when not in view of a CDA station is not clear. If this transmission ceases when not in view of a CDA station, then the potential availability increases dramatically except around CDA stations. These calculations assume a 5° elevation coverage footprint for the MetSats to a 0° horizon coverage contour for calculating the exclusion zone for Leo One USA transmissions. The Leo One USA communications coverage is computed for an elevation angle of 15°. Since Leo One USA is the largest Little LEO constellation, other Little LEO systems may experience less reduction in availability than Leo One USA.

The shared use of the LRPT bands provides 300 kHz of somewhat exclusive spectrum until 2002; the shared use of the TIP bands provides an additional 120 kHz of scarce spectrum.

If System B were to share the LRPT and TIP bands, but avoid GE Starsys, as suggested by the Notice, a total of 420 kHz is available. Initially, when one existing MetSat is overhead, half the TIP spectrum is available or 360 kHz. When two satellites are over head, none of the TIP spectrum may be available or 300 kHz total would be available. However, the TIP bands may not be used by all of the satellites. Occasionally when China's MetSat FY-1B is overhead a 50 kHz portion of the LRPT band would be unusable because of interference. Thus, at times, only 250 kHz may be available. This would be sufficient for subscriber communications and a

single gateway link which would provide satisfactory utility for this limited triple conjunction period.

In total, after 2006 there would be at most 120 kHz of exclusive spectrum available using the NOAA TIP channels. For a system such as the proposed Leo One USA system, this would require continued time sharing of the LRPT bands.

Normally, NOAA maintains a two satellite constellation consisting of an AM and PM satellite, currently NOAA 14 and NOAA 12. Figure 4 shows that if only a two satellite constellation is maintained by NOAA, the availability may remain high. However, as the constellation approaches the five satellites discussed by the Notice, then the availability decreases. The NOAA system is assumed to operate to 5 degrees. In determining the Leo One USA availability, the interference zone to NOAA is computed for a System B horizon coverage to the 5 degree NOAA coverage; the System B operations are computed for a 15 degree coverage in Figure 4. Figure 5 shows the improvement in availability that results at lower elevation coverage angles of 5, 10 and 15 degrees. Figure 6 shows the NOAA satellite constellation used for this evaluation.

These results show that there is ample availability at all latitudes for non real-time systems, and sharing is viable. Again, normally, NOAA maintains a two satellite constellation consisting of an AM and PM satellite (currently NOAA 14 and NOAA 12) but could have up to five satellites.
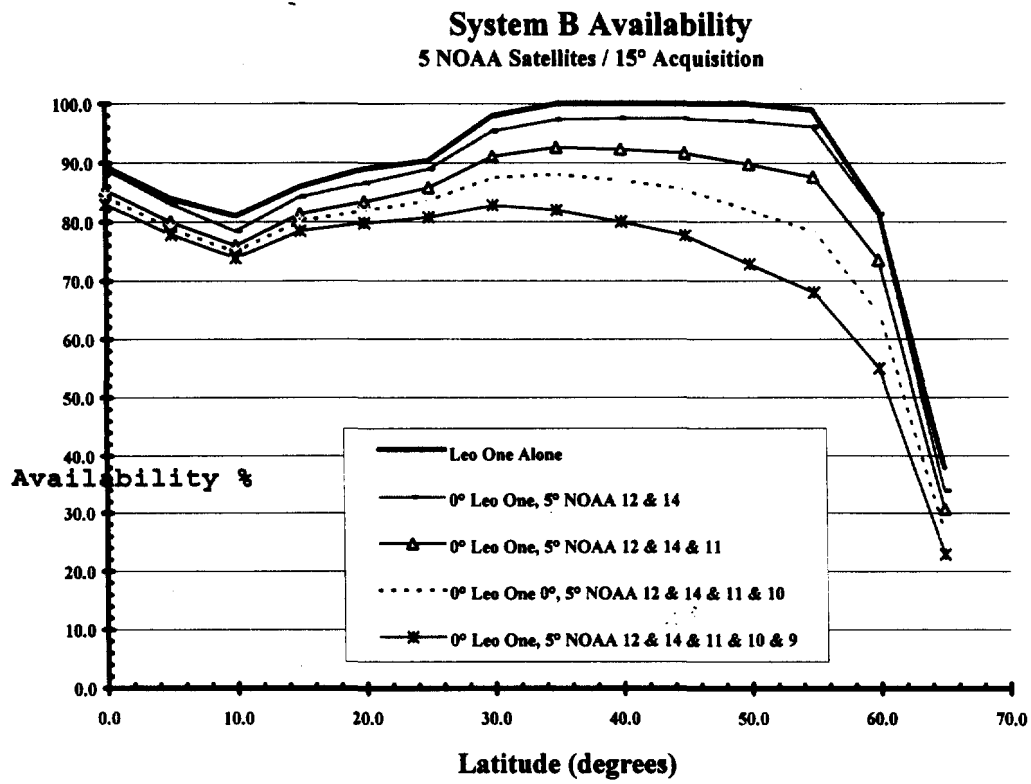
System B Availability
5 NOAA Satellites / 15° Acquisition

Figure 4. Availability For MetSat Band Sharing Of NOAA LRPT Bands As A Function Of The Number Of MetSats.

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System B Availability
5° NOAA Coverage To 0° Leo One

Availability %

5° Acquisition
10° Acquisition
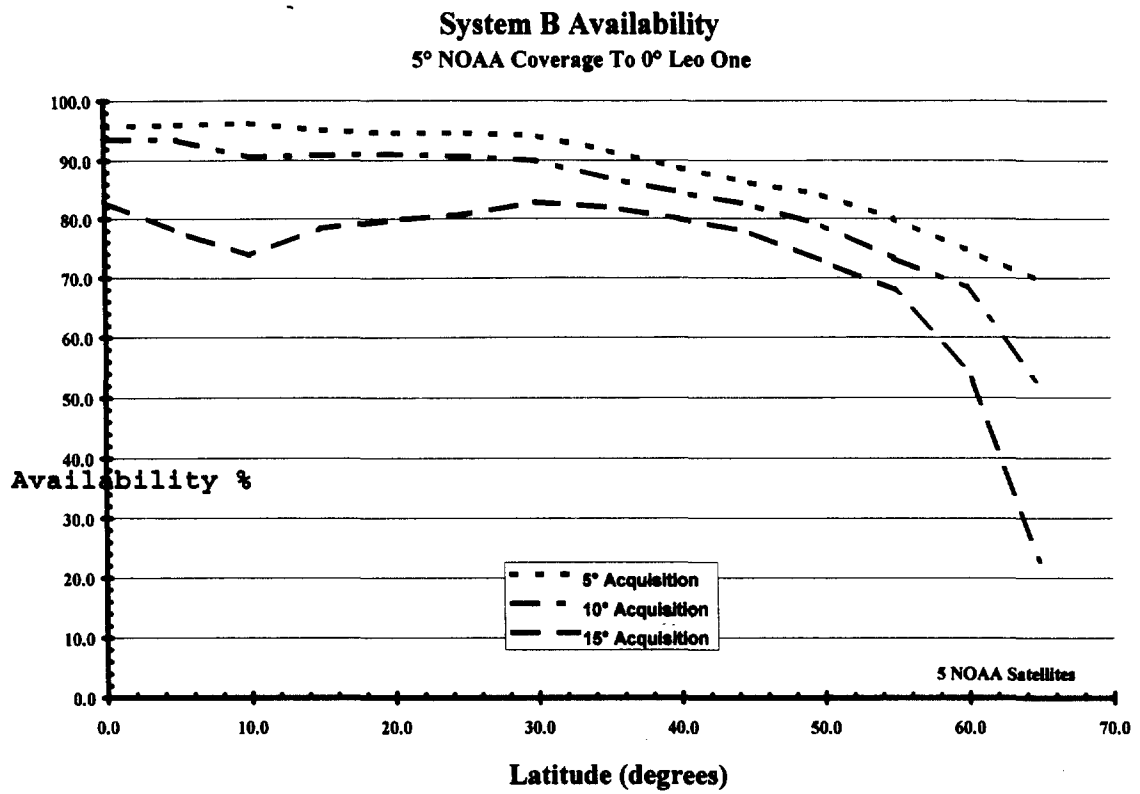15° Acquisition

5 NOAA Satellites

Latitude (degrees)

Figure 5. Availability For Sharing Of NOAA LRPT Bands Or TIP Channels.
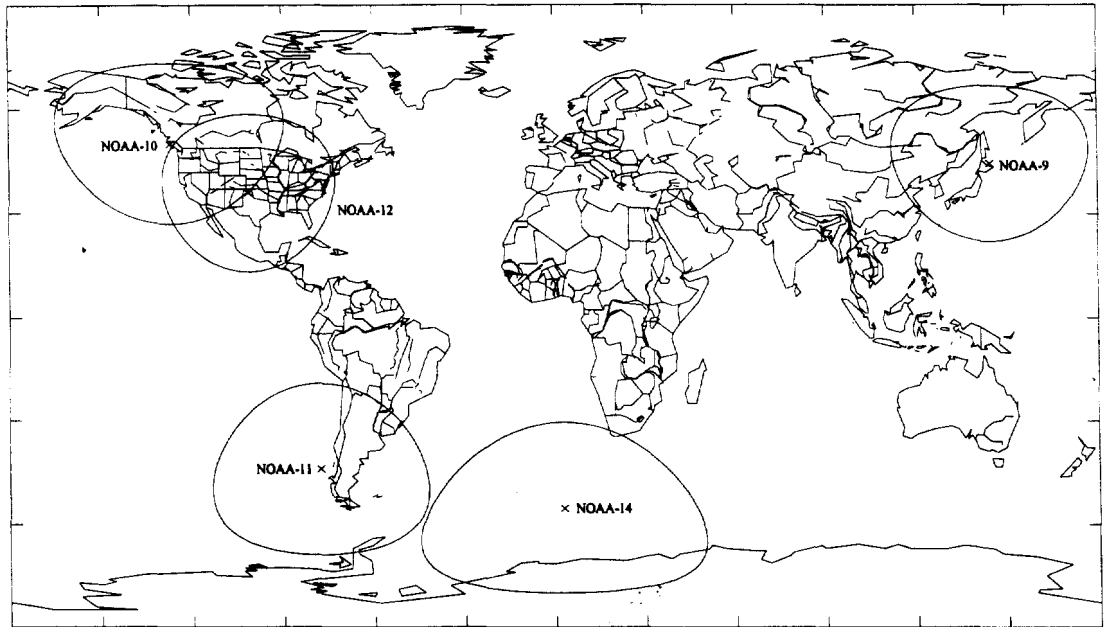
Figure 6. Five Satellite NOAA Constellation Coverage For 5° Elevation Footprint.

1.3.2 Concurrent Time Sharing of TIP Channels and LRPT Bands

During the transition period when a Little LEO must share both the NOAA channels and

the NOAA bands, the availability becomes a function of two sets of satellite constellations. One

set operating in the LRPT bands and one set operating in the TIP bands. For this situation, it

takes two satellites from each set to simultaneously be in contact with a System B satellite in

order to fully block communications. As a worse case analysis for the transition period, the

availability for a System B constellation has been computed for a five satellite NOAA

constellation based on the existing satellites along with a worse case of five future LPRT band

MetSats. For the purposes of evaluating this situation, an existing five satellite NOAA and an

existing five satellite DMSP constellation were chosen as offering representative orbit coverages.

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Figure 7 provides a snapshot in time of its world wide coverage. Using this worse case of five satellites each, the availability shown in Figure 8 was evaluated. As indicated, the user availability is high, much higher than sharing of just the LRPT bands or just sharing the TIP channels.

If we assumed two satellites in the LRPT bands and two satellites using the TIP channels, the availability is significantly better, as shown in Figure 9. The resulting availability is 100% except for around 10° latitude and above 60° latitude which are a function of the chosen Leo One USA constellation.

These results show that there is ample availability at all latitudes and that sharing is viable during this transition period.
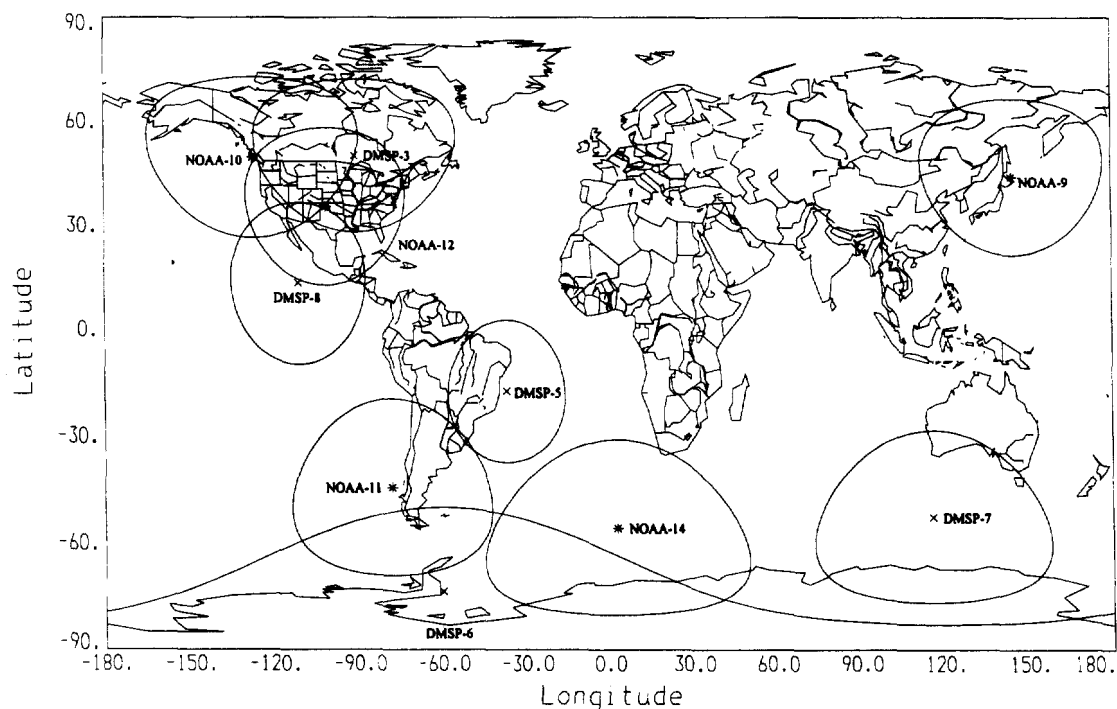

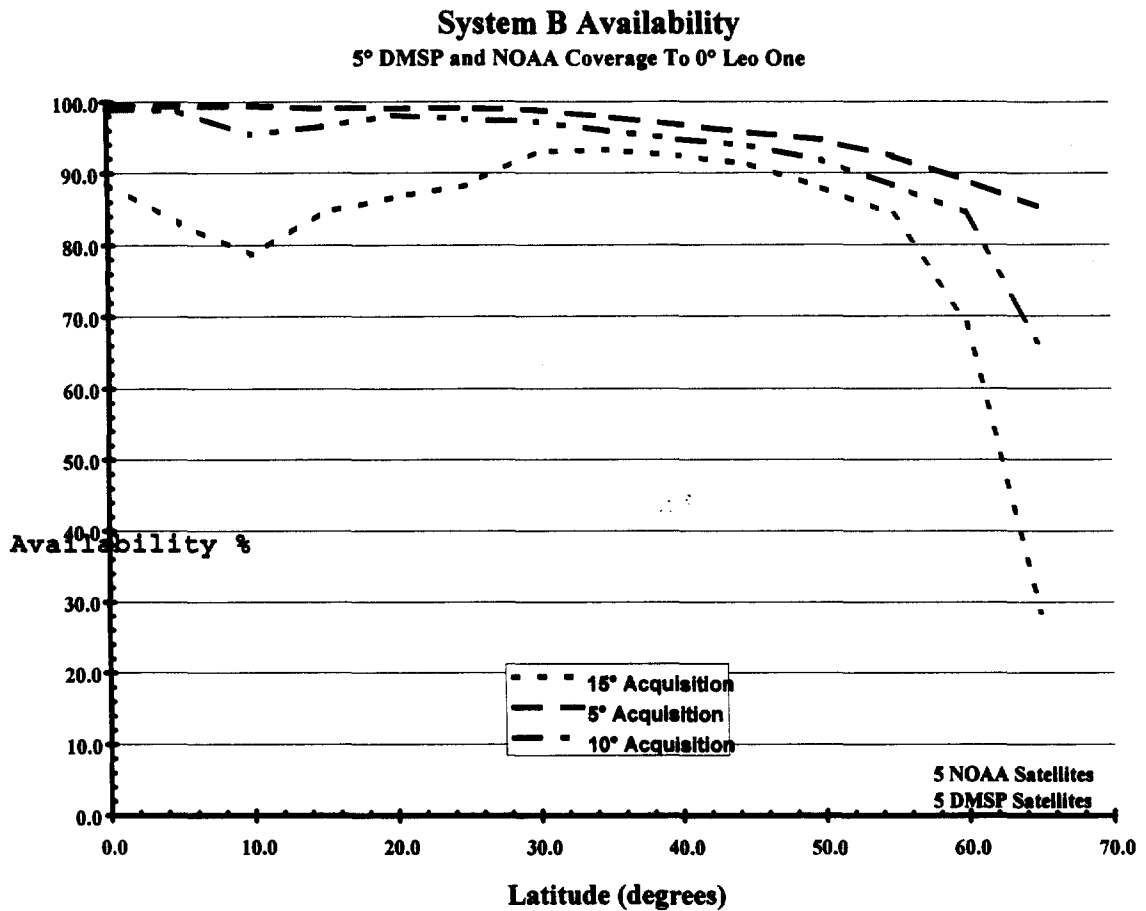Figure 7. Extended MetSat Coverage For Transition Period Analysis.

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System B Availability

5° DMSP and NOAA Coverage To 0° Leo One

Figure 8. Availability For Sharing Of LRPT Bands With Five MetSats and TIP Channels With Five NOAA Satellites.

System B Availability
2 DMSP and 2 NOAA Satellites
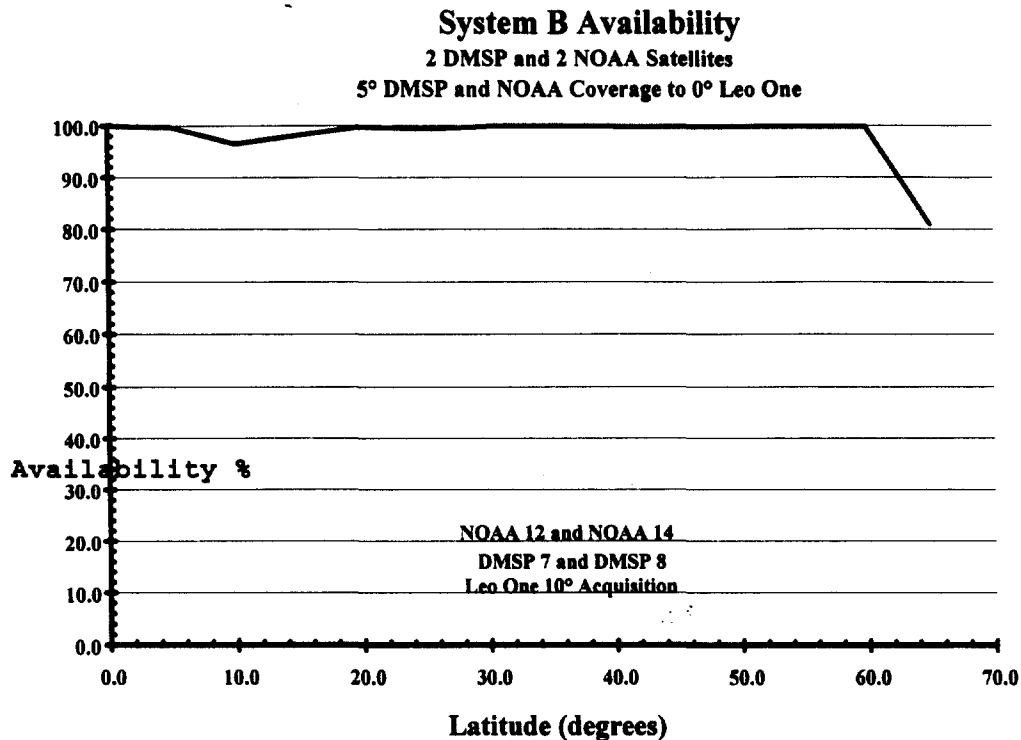5° DMSP and NOAA Coverage to 0° Leo One

Figure 9. Availability For Sharing Of MetSat LRPT Bands With Two NOAA Satellites and TIP Channels With Two NOAA MetSats.

1.3.3 Exclusive Use Of TIP Channels

After 2006, there would be 120 kHz of exclusive spectrum available using the NOAA TIP channels. Use of this spectrum would result in 100 percent availability. Continued sharing of the NOAA LRPT bands should be possible for increased capacity.

1.3.4 Incorporation Of ATP Channels

The NOAA APT channels represent a scarce spectrum resource of 50 kHz at 137.475-137.525 MHz and 50 kHz 137.595-137.645 MHz. The Notice describes these bands as providing 30 kHz at 137.485-137.515 MHz and 30 kHz 137.605-137.635 MHz. The Notice suggests that the Commission intends to allocate these bands to Orbcomm. This scarce spectral

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resource would be better served by making it available to a second round applicant. This would provide at least 60 kHz additional spectrum that would eventually be available exclusively after 2006. With more modern modulation approaches, Orbcomm can make better use of the spectral resource than wasting 20 kHz in guard bands in each channel, which is presumably a function of Orbcomm's modulation. Combined with the 120 kHz of NOAA TIP spectrum, a total of 220 kHz would become available to a second round applicant. This could make a significant difference to the necessity of continued sharing the LRPT bands with NOAA.

1.4 Sharing Requirements

In order to share the NOAA or DMSP frequency bands it will be necessary for the appropriate agencies to provide to the Little LEO operator an accurate ephemeris and the frequencies of operation of each MetSat. Likewise, it will be necessary for VITA to supply this information to other Little LEO operators sharing the VITA band. The ephemeris or element sets must be periodically updated to ensure their accuracy even if frequencies do not change. It is recommended that this be done on a weekly basis. While it is assumed that the MetSat frequencies are not changed often and that weekly updates are acceptable, more frequent updates could be accommodated.

The MetSat bands and VITA's channel are to be shared on a non-interference basis to the MetSats and VITA using a frequency avoidance concept. This simplified frequency sharing concept requires the Little LEO satellites to step or hop to the opposite MetSat band segment whenever a MetSat coverage footprint overlaps that of a Little LEO satellite horizon. The coincidence times are readily precomputed and frequency selection instructions can be loaded into each satellite to span the duration of element set validity (or seven days). The precomputed

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conflict situations for each seven day period must also include margin for timing and position accuracy and/or knowledge of both the MetSats or VITA and the Little LEO operator's constellation.

The use of daily planned uploads by Leo One USA allows for possible contact failures due to conflict situations. Each satellite is capable of seven days of autonomous operation using the preplanned timelines. If a command station contact has not been successfully performed within seven days, the satellite transmitter will be shut off until recontacted.

A satellite coverage blackout period is a preplanned event. Thus, network operations can potentially preschedule a broadcast of satellite blackout times for optimal message/page routing. The approach taken here may depend upon the specifics of each proposed Little LEO operator's network operations protocols. On the other hand, for those systems that do not attempt to provide near real-time messaging, this interval can be ignored as it would be transparent to the user.

Satellite timing must be maintained to assure proper scheduling of stored preplanned event timelines. This can be done via on-board GPS receivers or via command sessions and high stability clocks. Each command session can serve to check or resynchronize the satellite clock with UT.

Fail safe procedures can be implemented that minimize any interference that results from temporary soft or hard failures such as SEU and latchup events. In particular, Leo One USA plans to implement fail-safe procedures to ensure that a transmitter cannot be stuck in a transmit mode for more than one revolution.

For Leo One USA, it is estimated that, on the average, each satellite requires approximately 165 frequency changes over a seven day period. The additional hardened memory

to accommodate the required command timeline is inconsequential at approximately 1.7 Kbytes per satellite. The impact to the COCC command session is to increase a command upload time by approximately 33 milliseconds. Thus, Leo One USA does not see any impediment to implementing such a frequency sharing scheme.

Simplified frequency hop algorithms are possible that only require the impacted Little LEO satellite to change frequency. That is, there is no constellation ripple effect required. For System A, a dual DMSP conflict requires a hop to a VITA channel, if available, to assure high availability for near real-time services. In most cases, a hop frequency can be borrowed from another satellite plane during a conflict period. In all cases, conflict situation recognition requires a comparison of miss distance between a DMSP or NOAA satellite and a Little LEO satellite with the requisite coverage overlap distance. This is a trivial vector dot product computation using earth centered satellite position vectors.

Figure 10 shows a snap shot of the Leo One USA constellation coverage footprints with five DMSP satellites superimposed. A number of conflict situations are evident where more than one DMSP satellite coverage footprint overlaps a Leo One USA coverage footprint. These conflict situations and their time evolution are representative of those that have been analyzed for the required frequency hopping assignments giving Leo One USA high confidence in its ability to share with a MetSat constellation. Leo One USA will develop an algorithm for automating this process for its use.